SUMMARY OF VARIATIONS OF SONIC BOOM SIGNATURES RESULTING FROM ATMOSPHERIC EFFECTS

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ABSTRACT

Data based on about 5,000 overpressure measurements are presented to illustrate atmospheric induced sonic boom signature variations for supersonic aircraft varying in gross weight from about 20,000 to 450,000 pounds and from about 60 ft. to 185 ft. in length, respectively. Descriptions are included of several special flight test experiments performed to define quantitatively some of these atmospheric effects.

The experience derived from several flight test programs regarding sonic boom signature variations has been summarized. Variations were noted to occur in the peak overpressure, the impulse function, the time duration, and the bow wave rise time. Such variations are noted to be induced by the atmosphere. That portion of the atmosphere below about 2,000 ft is shown to be most influential although in some cases the higher portions may also be important. Aircraft motions, in the form of perturbations about the normal flight track, are shown not to contribute significantly to observed sonic boom signature variations at the ground.

INTRODUCTION

It is a matter of record that substantial variations occur in sonic boom signature shapes (See refs. 1, 2, and 3.). These variations involve such quantities as the peak overpressure, the time duration, impulse, etc. Such variations are thought to be largely due to atmospheric and weather effects although the exact cause and effect relationship has not been definitely established up to this time. The purpose of this paper is to present some recent sonic boom measurement results which illustrate the nature of the atmospheric effects problem and which define quantitatively some of these effects.

Figure 1 contains examples of wave shapes observed for three different types of aircraft. At the left of the figure are tracings of measured waves for the F-104 aircraft for which the time duration is about .10 of a second. It is seen that the waves vary from sharply peaked to gently rounded. Similar signature tracings are shown at the right side of the figure for the B-58 and the XB-70, respectively. The B-58 signatures are roughly .20 of a second in

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duration and those of the XB-70 are approximately .30 of a second in duration. The main differences between waves for a given aircraft are noted to occur at the times of the rapid compressions. The largest overpressure values are generally associated with the sharply peaked waves.

NATURE OF SIGNATURE SHAPE VARIATIONS

In the following discussions, reference will be made to variations in those quantities which are defined in figure 2. Shown in figure 2 is an example tracing of an N-wave signature. The quantities peak positive overpressure Δp, the positive impulse I, the total time duration of the wave Δt, and the rise time τ , are illustrated. Rise time always refers to the bow wave and is usually defined as the elapsed time between the onset of pressure and the occurrence of its maximum value (See ref. 4.).

There has been considerable discussion about the frequency response requirements of measuring equipment and whether differences in frequency response would markedly change the observed patterns of signature variation. In order to provide some information in this regard, FM magnetic tape records were processed by playback through a series of low pass filters. Figure 3 contains examples of traced wave forms resulting from playback of one particular record through various filters varying in band width from about 5,000 Hz down to about 200 Hz. For the case illustrated, it is seen that the narrower band width systems noticeably affect the wave shape particularly with regard to the peak overpressure and rise time. About 200 data records were processed as indicated in figure 3 to provide data for the histograms of figure 4.

The data of figure 4 relate to B-58 flights at an altitude of about 31,000 ft. and a Mach number of 1.5. In the figure the number of events is plotted as a function of the overpressure values in histogram form for the four different filter band widths of figure 3. The data of figure 4 relate to a variety of wave form shapes on the original records such as those illustrated in figure 1. It can be seen from the inspection of figure 4 that the histograms do not vary markedly as a function of filter band width. There is, however, a general shift to lower peak overpressure values as filter band width is reduced. The point can be made that the average peak overpressure values obtained for the smaller filter band width are more nearly in agreement with the calculated values than are those obtained with the larger filter band widths. For all the data subsequently presented in this paper the instrument frequency responses are essentially .02-5,000 Hz and thus the effects noted in figures 3 and 4 will not apply.

Shown in figure 5 are probability plots of the ratios of measured to calculated overpressure for the B-58 and XB-70 aircraft. The ordinate is the probability of equalling or exceeding a given abscissa value. Three sets of data are included. The square data points for the XB-70 and the triangle data points for the B-58 were obtained from measurements of a 7,000 ft. linear microphone array, whereas the circle B-58 data points were obtained for a small cruciform microphone array having dimensions of 200 ft. It should be noted that the data would fit on a straight line if the variation corresponded to a normal distribution. The slope of this line would indicate the amount of variability of the data, a vertical line indicating no variability. With the exception of the highest and lowest valued points all three sets of data generally follow a normal distribution line and the variability is about the same in each case. These results are similar to those obtained in other programs as, for instance, in references 1 and 2, and the implication is that the type and size of the airplane are not significant factors regarding variability.

Although no data on the positive impulse function of the waves are included in this paper, the point can be made that the same general trends exist as for the overpressure data of figure 5. The only exception is that the variability is generally less for the impulse function for a given set of flight and atmospheric conditions than for the overpressure function.

Some variations in the sonic boom signature time durations which are important for structural responses have been observed. The data of figure 6 illustrate these latter variations for the B-58 aircraft for two different flight conditions. Results are based on about 200 data points measured at a fixed location for approximately 50 flights over a period of about three weeks. The histograms at the top of the figure are for an overhead flight track, for an airplane altitude of 31,000 ft., and for a Mach number of 1.5. The histogram at the bottom of the figure relates to a flight track five miles distant from the measuring station and for an airplane altitude of 43,000 ft. and a Mach number of 1.65. It can be seen that the time periods are longer for the off the track condition but that variability does exist in the durations of the waves at both locations. This variability is probably due to differences in the propagation rates of the bow and tail waves which travel along somewhat different ray paths from the aircraft to the ground.

Also of interest is the variation in bow wave rise time as defined in figure 2, since it is believed that this quantity is important from a subjective reaction standpoint. The data of the histograms of figure 7 have been normalized on the horizontal scale to indicate the rise time per unit overpressure. These data are for a B-58 aircraft for an altitude of approximately 31,000 ft. and a Mach number of 1.5 for an overhead flight condition. The two histograms of the figure relate to the same measured data but result from different interpretations of that data. For instance, the histogram of solid lines is based on the rise time definition of figure 2. The dashed line histogram on the other hand is based on the determination of the Δp values associated with the first peak in the wave even though that may not be the highest peak. This latter definition may be the more appropriate one for subjective evaluation whereas the definition of figure 2 is a commonly accepted one. In either case it can be seen that considerable variations in rise times are encountered regardless of the manner in which rise time is defined. It is significant to note that rise times of less than a milli-second are commonly encountered for the initial peak of the wave.

PROPAGATION STUDIES IN THE LOWER ATMOSPHERE

Previous studies of atmospheric effects on sonic boom signatures have suggested that the lower layers of the atmosphere exert the greatest influence (See ref. 3.). In order to better define the region of the atmosphere most effective in distorting the sonic boom signatures, several special experiments have been performed by NASA and USAF personnel. The first two of these were conducted at the NASA Wallops Station and are illustrated schematically in figures 8 and 9. Flights were made over an instrumented range consisting of a linear microphone array on the ground and extending about 1,500 ft., in combination with a vertical array on an instrumented tower extending to about 250 ft. above the ground surface. The generating aircraft was flown at an altitude of 40,000 ft., and at a Mach number of 1.5 for a variety of weather conditions. The objective of the studies was to correlate the sonic boom measurements with the extensive meteorological data obtained on the instrumented tower.

In situations where wave form distortion was noted to exist, it was found that similar wave shapes were measured both at the ground surface and on the instrumented tower. A particularly interesting and significant result of these studies is illustrated by the wave form tracings of figure 8 which suggest that similar types of distortions exist at points along given ray paths. Such a result was obtained along a ray path extending from a measuring station on the tower to the ground and also on a reflected path from the ground back up to a station on the tower.

This leads to the conclusion that for these particular tests the 250 ft. layer of the atmosphere near the surface of the ground did not appreciably affect the signature shapes. Thus, correlation studies involving only the lower surface layers would probably not produce conclusive results. It follows then that the portion of the atmosphere above 250 ft. was important for the conditions of this experiment regarding wave shape distortions.

As a follow up to the ray path experiments of figure 8, another experiment was performed to investigate the effects of time with regard to atmospheric distortion effects. This experiment was performed with the aid of two airplanes of the same type which were flown at the same altitude and Mach number and on the same nominal flight track and about 5 seconds apart. By means of a ground microphone array it was possible to measure sonic boom signatures which travelled along essentially the same ray path from high altitude to the ground for a distance of approximately 15 miles but at slightly different times. One of the results of the experiment is illustrated by the signature tracings at the bottom of figure 9. It can be seen that quite different wave shapes are associated with measurements at times a few seconds apart. Such a result suggests that the integrated effects of changes in the atmospheric conditions along a given ray path may be significant even for such a small difference in time.

Further experiments relating to atmospheric effects on sonic boom propagation were performed recently by NASA and USAF personnel in the Edwards, California, area. One of these experiments was performed with the aid of the Goodyear airship, Mayflower, as illustrated schematically in figure 10. For some cases as illustrated in the figure the incident signature was essentially undistorted whereas the ground measurements and the reflected signature measurements at the airship showed evidence of distortion. This would suggest that the 2,000 ft. surface layer of the atmosphere was responsible for all such distortion. On the other hand some other measurements indicate distortion of the incident wave thus indicating that the portion of the atmosphere above 2,000 ft. may for some cases be important.

None of the above experiments produced evidence of direct correlation between signature distortion and identifiable local disturbances in the atmosphere. The last special experiment to be described was performed particularly to achieve such a correlation. Use was made of a large subsonic aircraft to generate wing tip vortices in the test area in such a manner that the shock wave to be measured would pass through these vortex disturbances (See ref. 5.). The resulting measurements of peak overpressure values from the microphones in the ground array are shown at the bottom of figure 11. Of particular interest are the data points at distances from 5,200 to 5,600 ft. along the ground track where markedly larger overpressure values were recorded. These latter measurements were believed to have been affected by the presence of the wing tip vortices, but no significant changes were noted in the signature shapes. Some further analyses and more definitive experimental studies are planned to improve the understanding of these latter interaction phenomena.

EVALUATION OF AIRCRAFT MOTION EFFECTS

It is recognized that measurements of sonic boom signatures on the ground may be affected by variations in the aircraft operating conditions as well as by the atmosphere. An experiment has thus been performed in an attempt to evaluate the effects on measured signatures of perturbations of the aircraft about its nominal flight path. In order to accomplish this study the test setup of figure 12 was made use of. The aircraft was flown at a given altitude and Mach number and on a given heading directly over and along a 7,000 ft. long array of 40 microphones. The aircraft which was specially instrumented to record its motions was flown both in steady level flight and in "porpoising" flight. All flights were accomplished at an altitude of 35,000 ft. and a Mach number of 1.5 with an F-106 aircraft. For the porpoising flight the pilot caused the airplane to deviate from the nominal flight track by cycling the controls to produce a $\pm$ 0.5 g normal acceleration at the center of gravity of the aircraft. These induced motions have a period of about one second and thus the wave lengths of the motion were about 1,600 ft. for these particular flight conditions.

Ground overpressure measurements for the two types of flights are shown in figure 13. The data points for three steady flights and for four porpoising flights were obtained from individual microphones located at various stations along the ground track as indicated schematically in figure 12. It can be seen from figure 13 that approximately the same ranges of overpressure were measured for each of the flight conditions. Furthermore, an inspection of the data of figure 13 suggests the occurrence of cyclic variations of the overpressures for both flight conditions. Such cyclic variations have been documented during this and other flight research programs (See ref. 1.). It is significant to note, however, that cyclic variations that occur during the steady flights seem to have wave lengths that vary considerably. Since it is believed that the porpoising flight condition might produce a cyclic variation of overpressure at a preferred wave length on the ground, the data of several such flights were analyzed in such a manner as to accentuate this effect if it existed. These results are shown in figure 14.

The individual histograms of figure 14 represent variations in the absolute values of the differences in the overpressures measured at pairs of points which are separated by the distances indicated. If the effects of the airplane motion were faithfully transmitted to the ground, it is reasonable to expect that smaller differences in overpressure values would be obtained at some separation distances than at others. The sample data of figure 14 represent separation distances varying from 100 ft. to 1,600 ft. for comparison. In order to better define the trend of the variations of figure 14 the data are presented in a more convenient form in figure 15.

In figure 15 the quantity $\sigma_{\Delta p}$, which is the root mean square overpressure difference, is plotted as a function of separation distance for the distances for which data are available. The curve of figure 15 seems to represent generally the variation of $\sigma_{\Delta p}$ as a function of distance for both the steady and porpoising flight cases. Both sets of data are seen to increase monotonically as a function of separation distance. Such a result strongly suggests that perturbations about the flight track of the order of those illustrated in figure 12 do not propagate faithfully to the ground from high altitude. It is thus believed that the variations discussed previously in this paper are due mainly to atmospheric effects rather than to effects of aircraft motion.

CONCLUDING REMARKS

The experience derived from several flight test programs regarding sonic boom signature variations has been summarized. Variations were noted to occur in the peak overpressure, the impulse function, the time duration, and the bow rise time. Such variations are noted to be induced by the atmosphere. That portion of the atmosphere below about 2,000 ft. is shown to be most influential although in some cases the higher portions may also be important. Aircraft motions, in the form of perturbations about the normal flight track, are shown not to contribute significantly to observed sonic boom signature variations.

REFERENCES

1. Hilton, David A.; Huckel, Vera; Steiner, Roy; and Maglieri, Domenic J.: Sonic-Boom Exposures During FAA Community-Response Studies Over a 6-Month Period in the Oklahoma City Area. NASA TN D-2539, 1964.

2. Hilton, David A.; Huckel, Vera; and Maglieri, Domenic J.: Sonic-Boom Measurements During Bomber Training Operations in the Chicago Area. NASA TN D-3655, 1966.

3. Hubbard, Harvey H.; Maglieri, Domenic J.; Huckel, Vera; and Hilton, David.: Ground Measurements of Sonic-Boom Pressures for the Altitude Range of 10,000 to 75,000 Feet. NASA TR R-198, 1964.

4. Maglieri, Domenic J.; Parrott, Tony L.; Hilton, David A.; and Copeland, William L.: Lateral-Spread Sonic-Boom Ground-Pressure Measurements From Airplanes at Altitudes to 75,000 Feet and at Mach Numbers to 2.0. NASA TN D-2021, 1963.

5. Wetmore, Joseph W.; and Reeder, John P.: Aircraft Vortex Wakes in Relation to Terminal Operations. NASA TN D-1777, 1963.

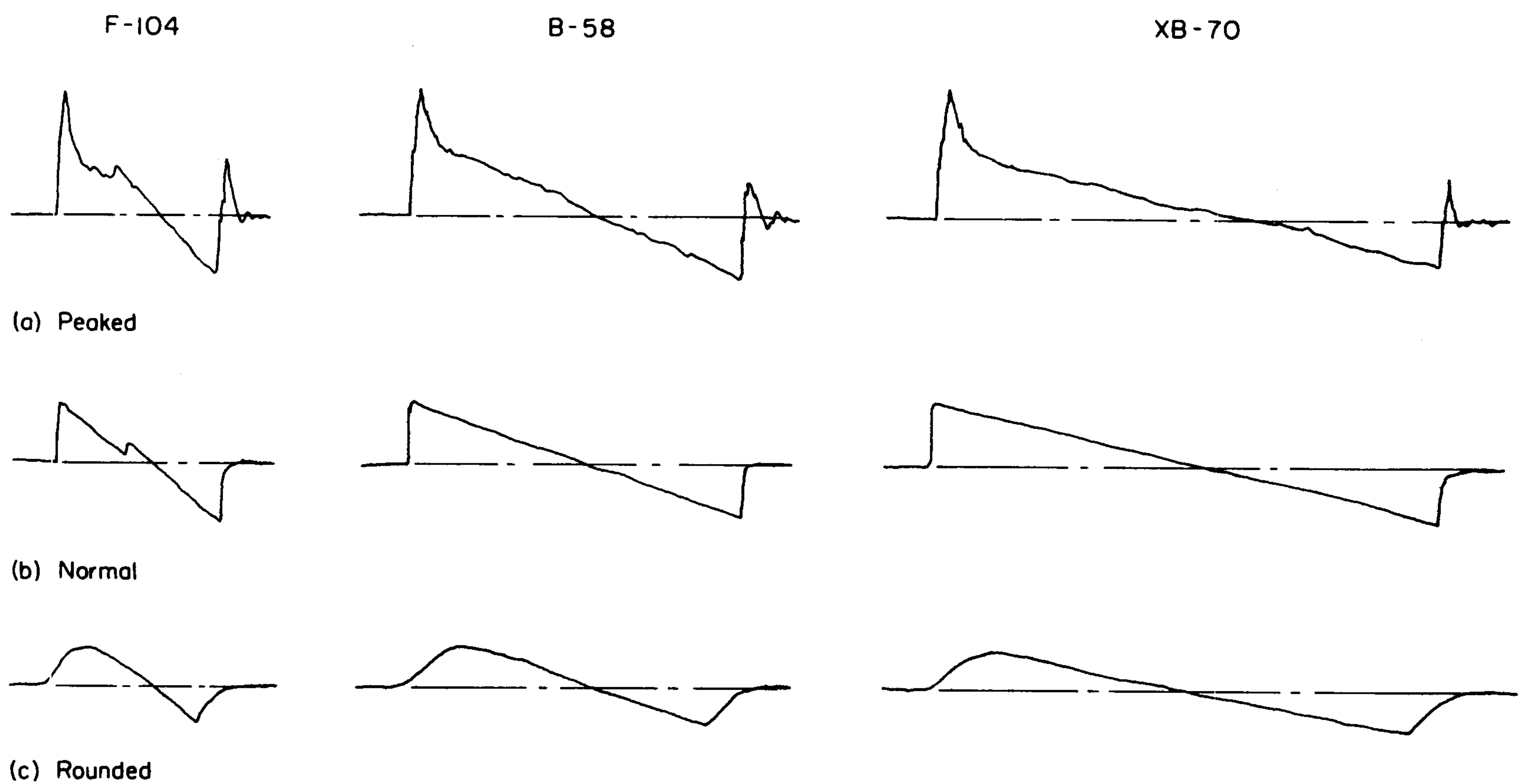


Figure 1.- Variation of measured sonic boom pressure signatures at ground level for small, medium, and large aircraft in steady level flight.

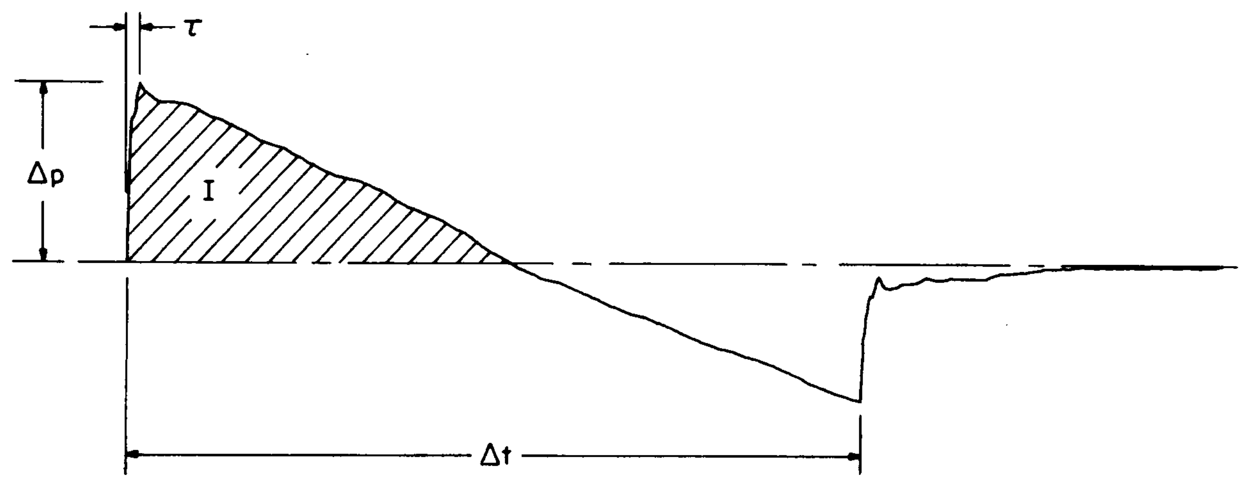


Figure 2.- Definitions of quantities.

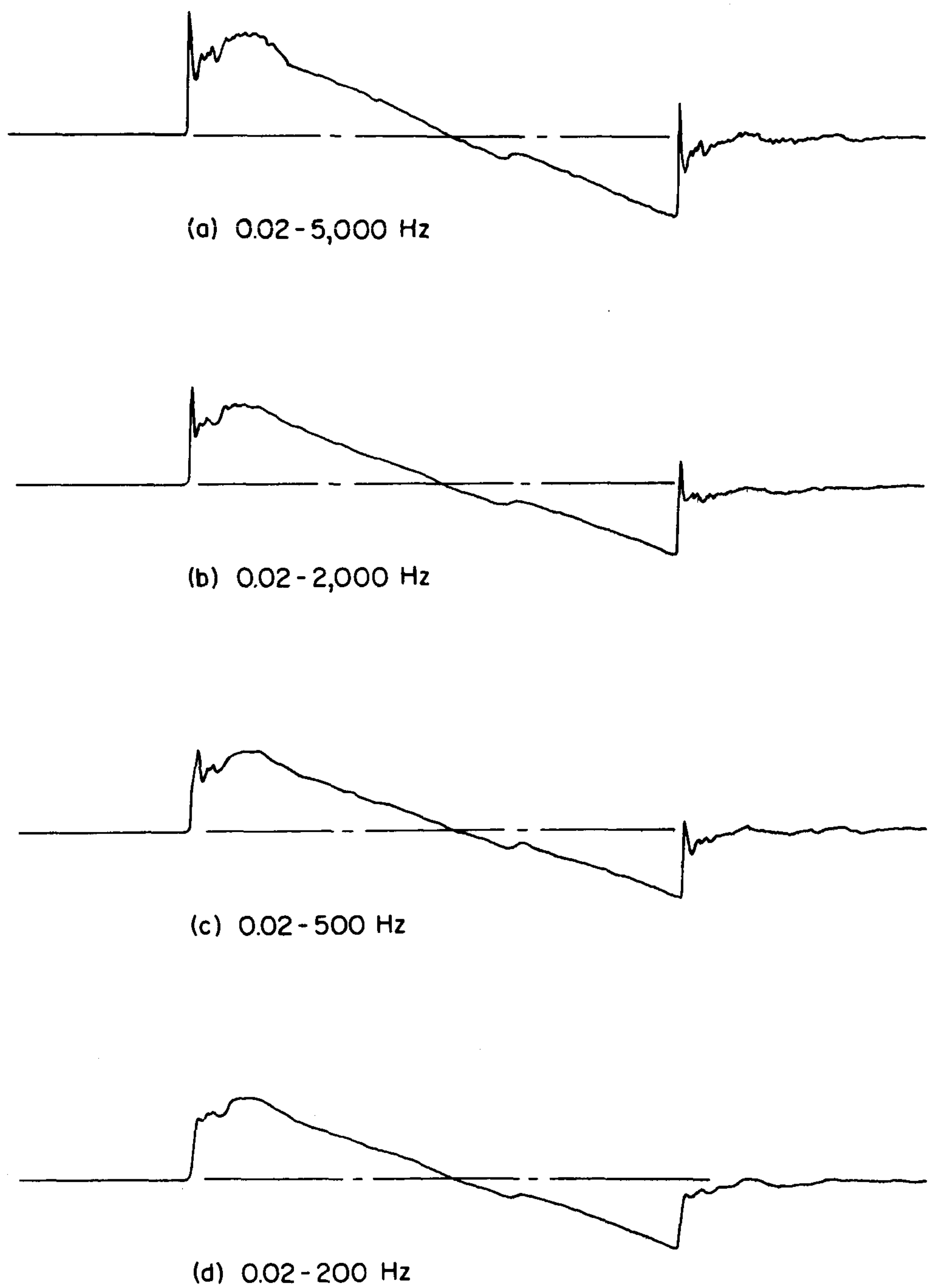


Figure 3.- Effects of instrument frequency response on sonic boom signature shapes. Data are for B-58 aircraft at an altitude of 31,000 ft. and a Mach number of 1.5.

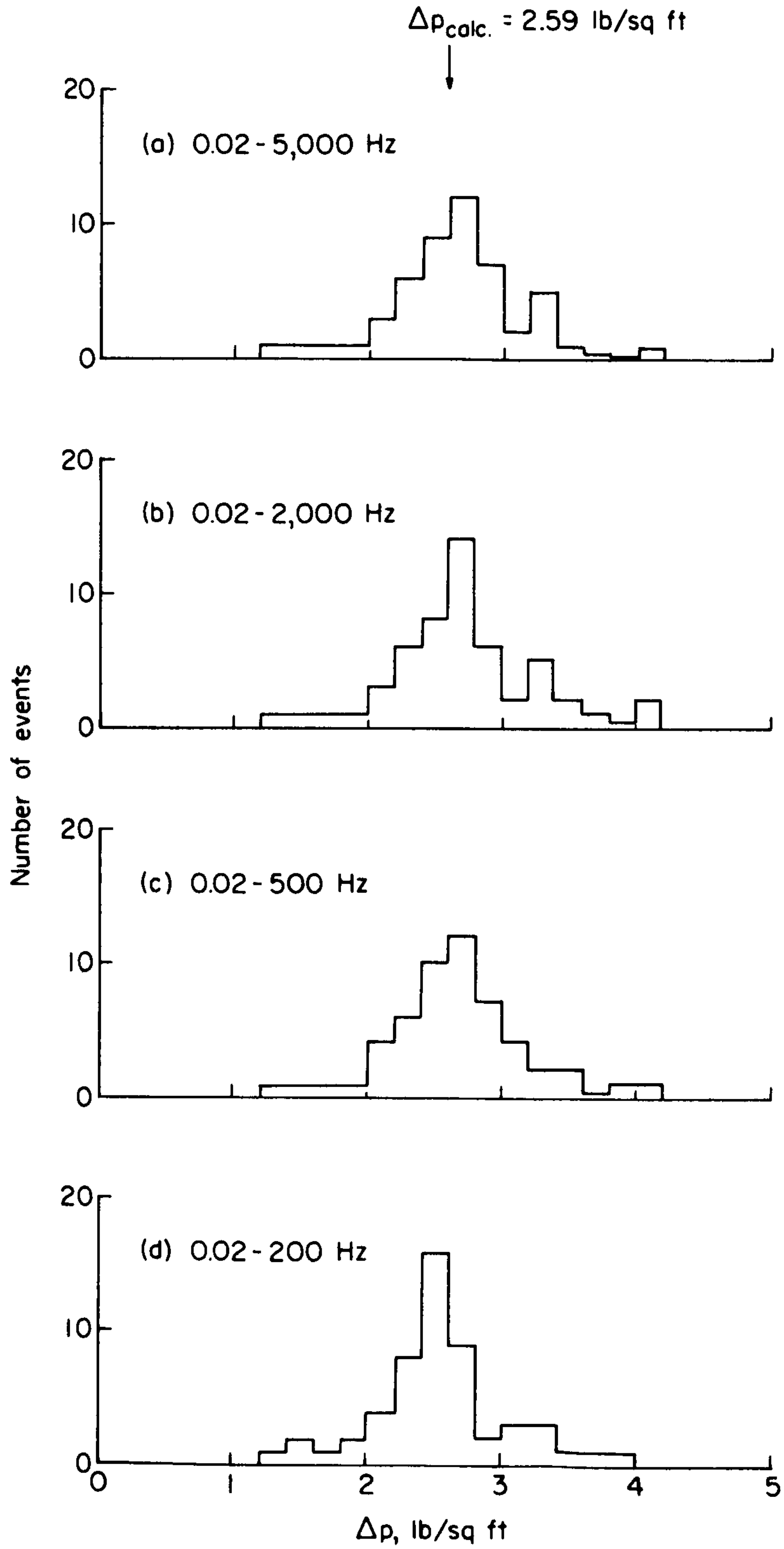


Figure 4.- Variation of peak positive overpressure from sonic boom signatures analyzed at various frequency response ranges. Data are for B-58 aircraft at an altitude of 31,000 ft. and a Mach number of 1.5.

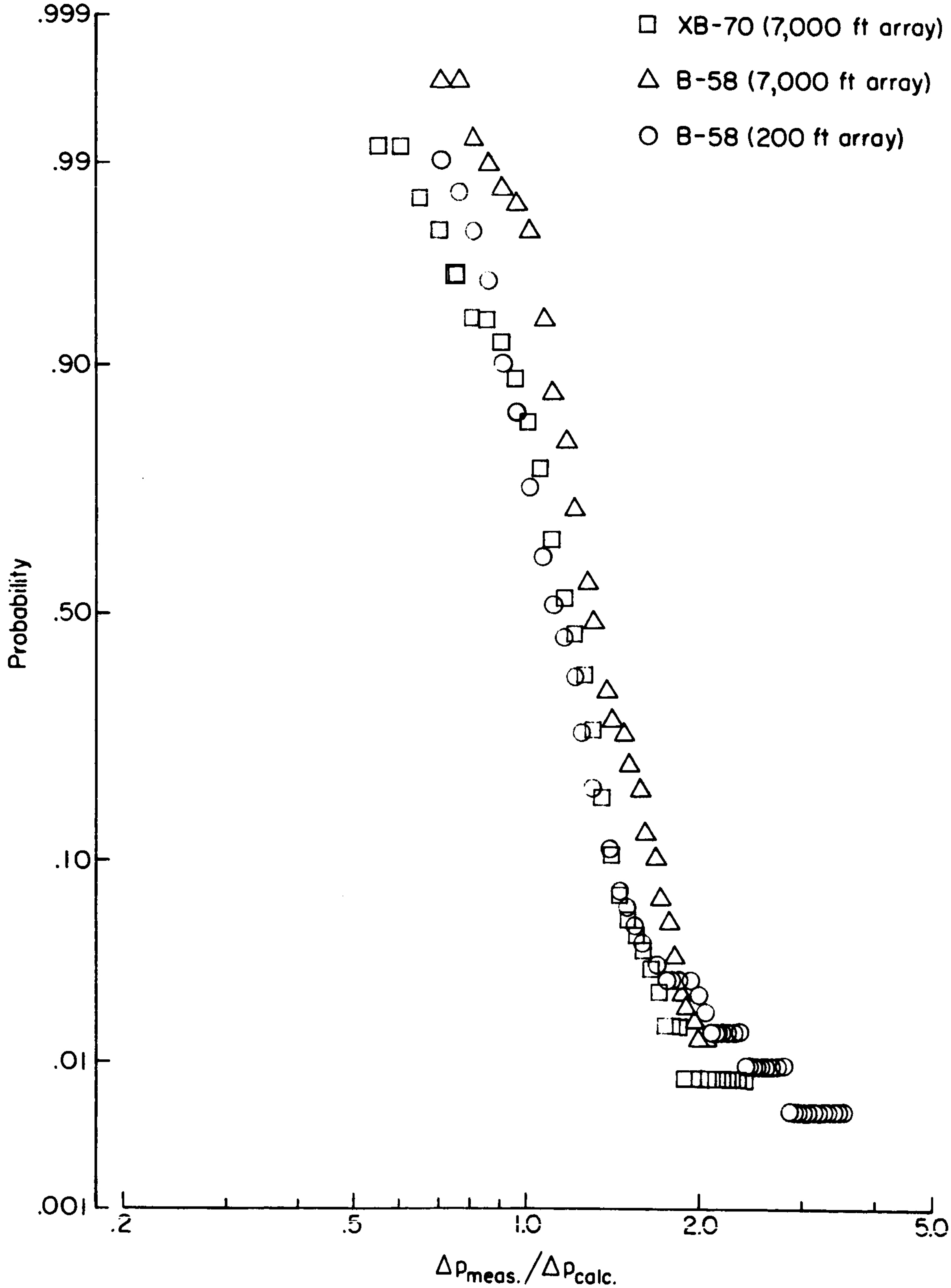


Figure 5.- Probability of equaling or exceeding a given value of the ratio of measured to calculated overpressures for two different aircraft. (Data are plotted on log normal probability paper.)

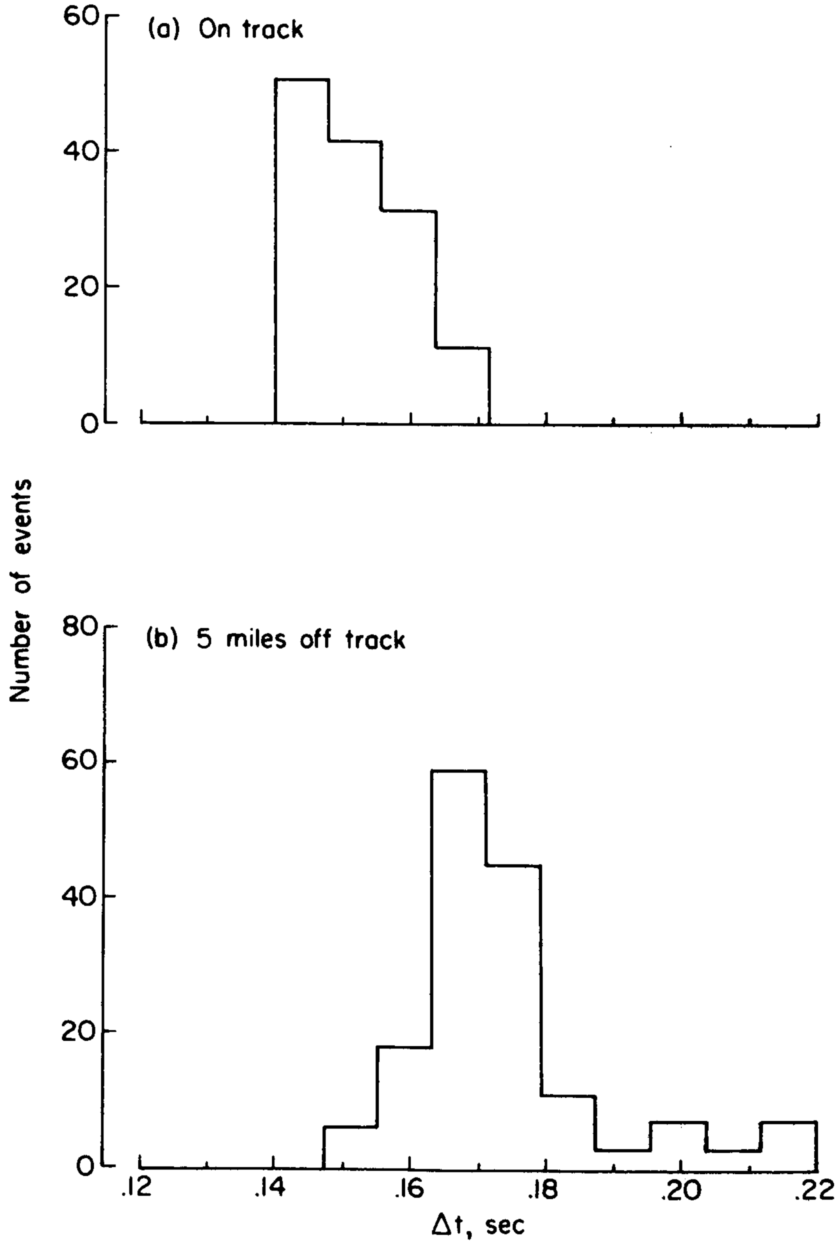


Figure 6.- Variations of sonic boom signature time durations for two different flight conditions of the B-58 aircraft.

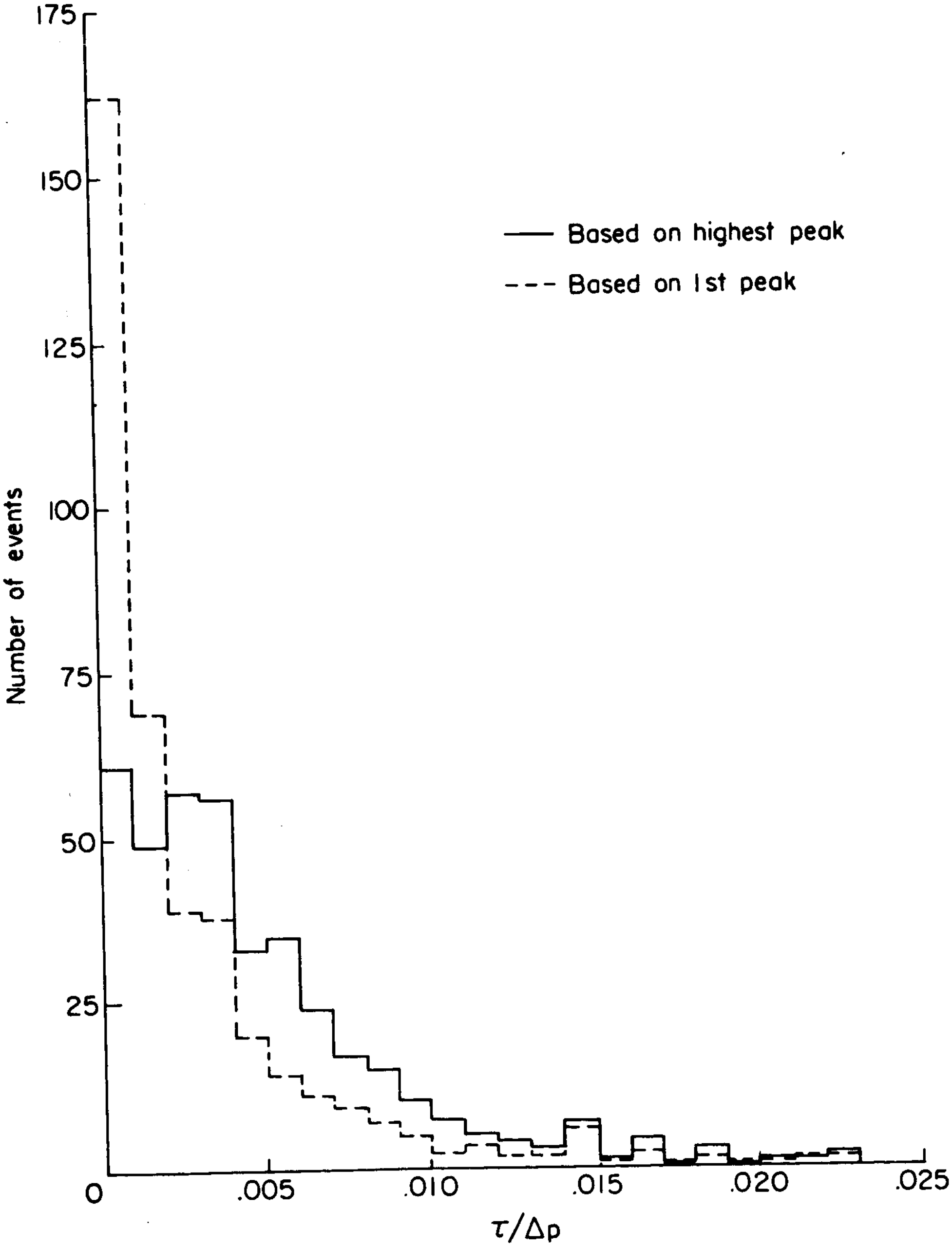


Figure 7.- Variations of bow wave rise time for the B-58 aircraft at a Mach number of 1.5 and an altitude of 31,000 ft.

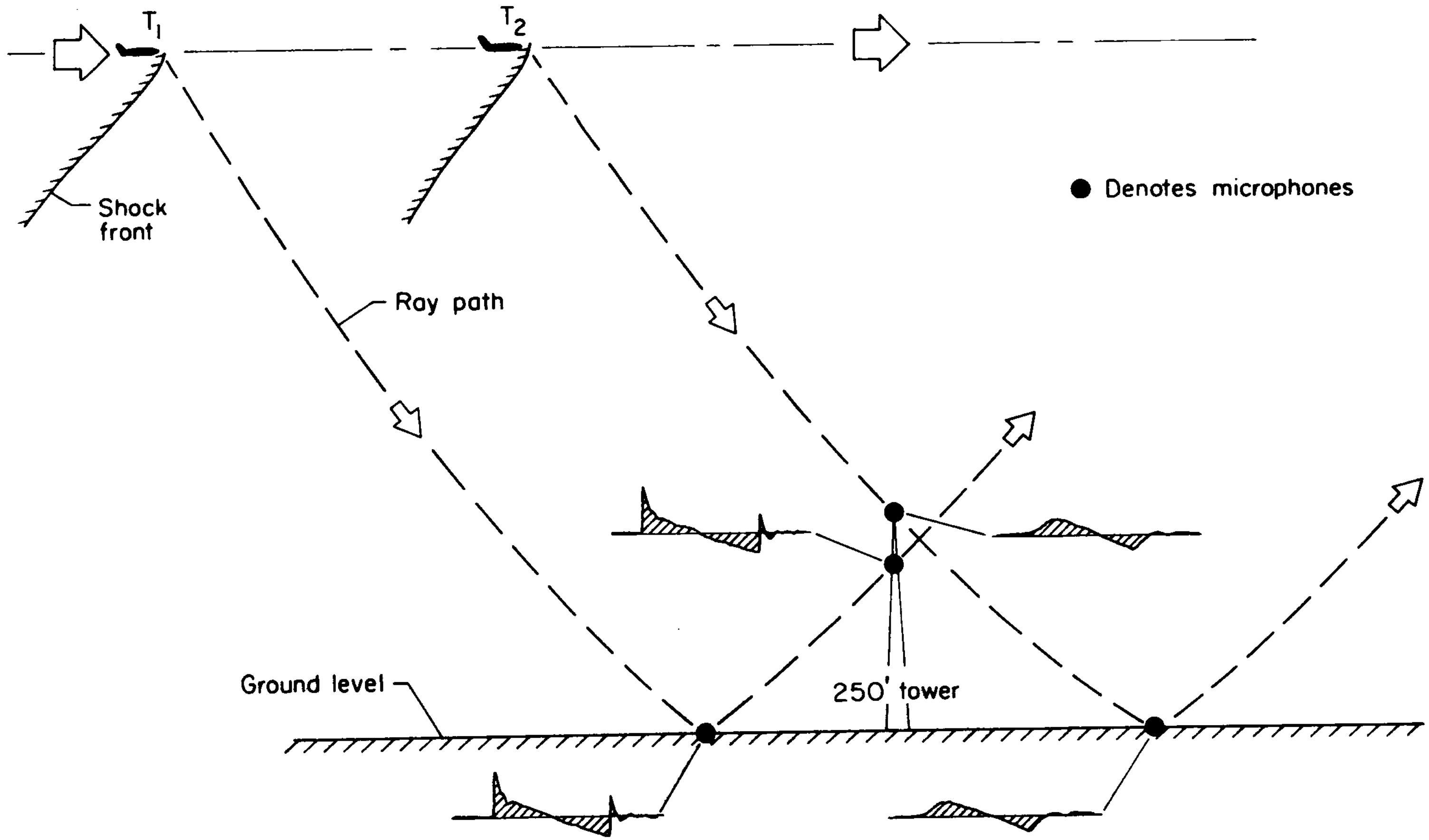
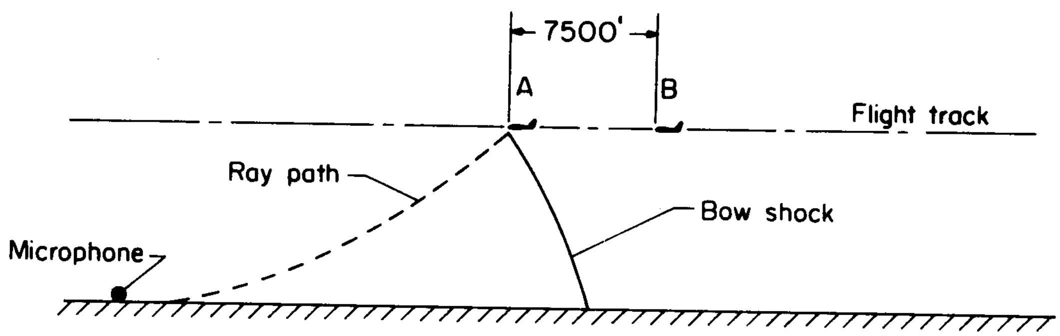
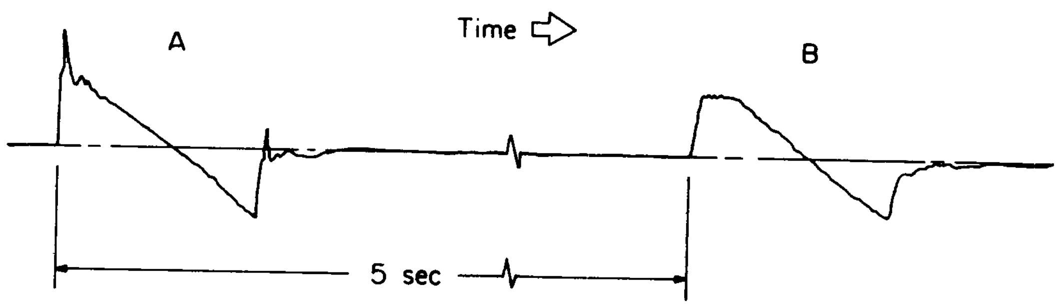


Figure 8.- Schematic diagram of test setup at the NASA Wallops Station, Virginia, for evaluating atmospheric effects on sonic boom wave propagation in the surface layer (250 ft. depth) of the atmosphere. Generating aircraft was an F-106 at 40,000 ft. altitude and a Mach number of 1.5.



(a) Schematic of shock front and ray path



(b) Sonic boom ground pressure signatures

Figure 9.- Schematic diagram of test arrangements at NASA Wallops Station, Virginia, for measuring sonic boom signatures from two aircraft at the same flight conditions and for a very short time interval.

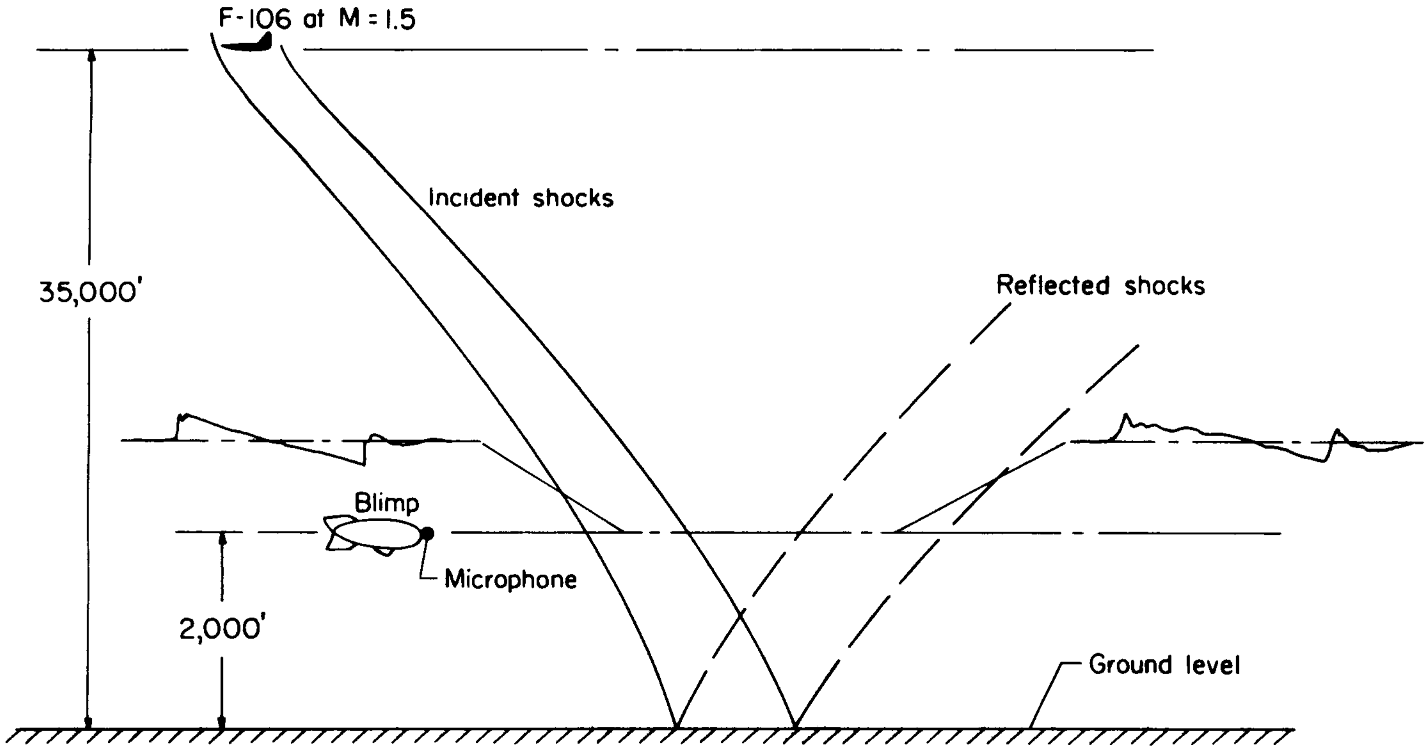


Figure 10.- Schematic diagram of test arrangements at Edwards, California, for evaluating atmospheric effects on sonic boom wave propagation in the lower layer (2,000 ft. depth) of the atmosphere. Generating aircraft was an F-106 at 33,000 ft. altitude and a Mach number of 1.5.

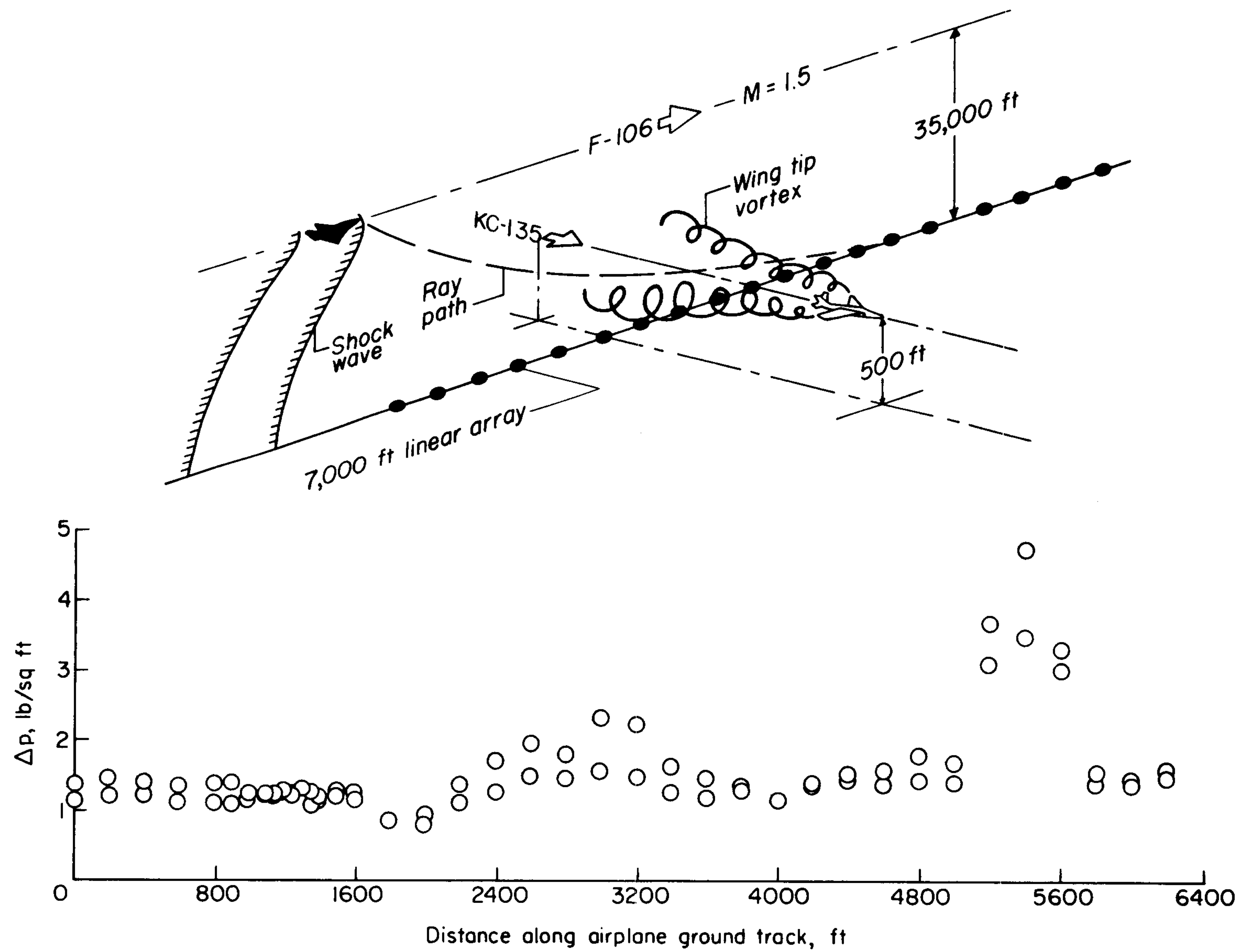


Figure 11.- Schematic diagram of test arrangements in the Edwards, California, area for studying the phenomenon of shock wave-vortex interactions.

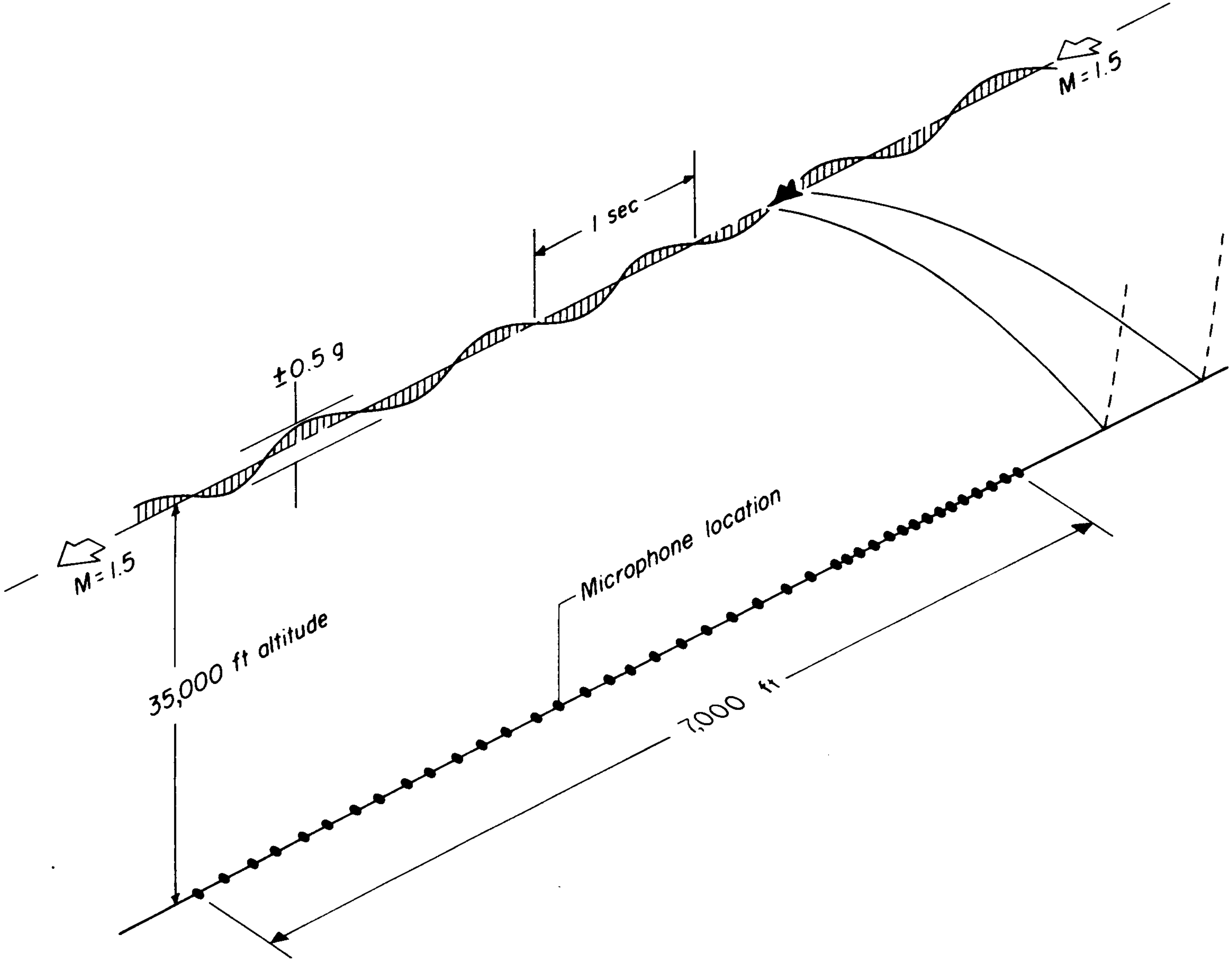


Figure 12.- Schematic diagram of test arrangements in the Edwards, California, area for evaluating the effects of airplane motions on sonic boom signatures at the ground.

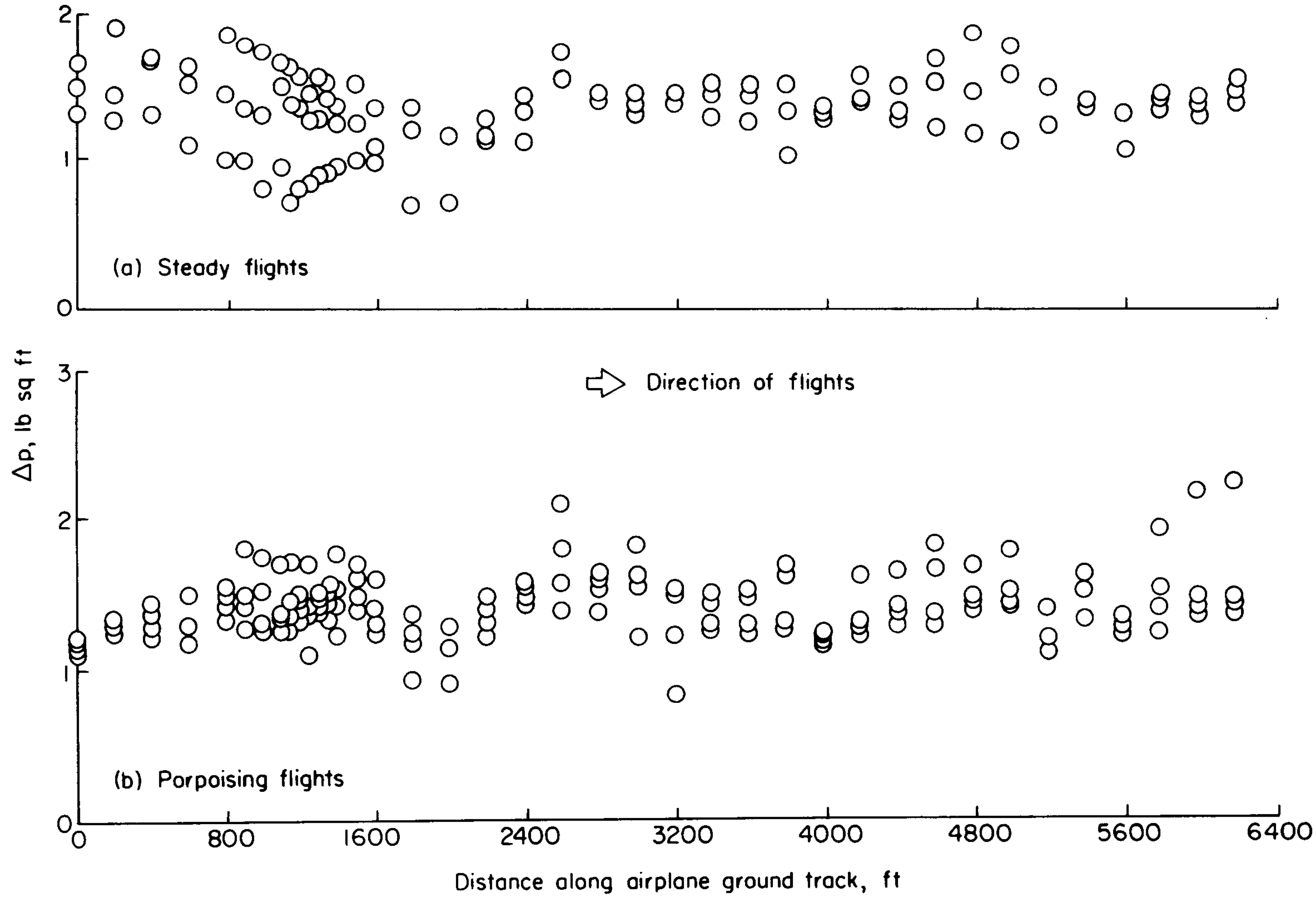


Figure 13.- Measured peak overpressures at several stations along the ground for both steady and porpoising flights of an F-106 aircraft at 35,000 ft. altitude and a Mach number of 1.5.

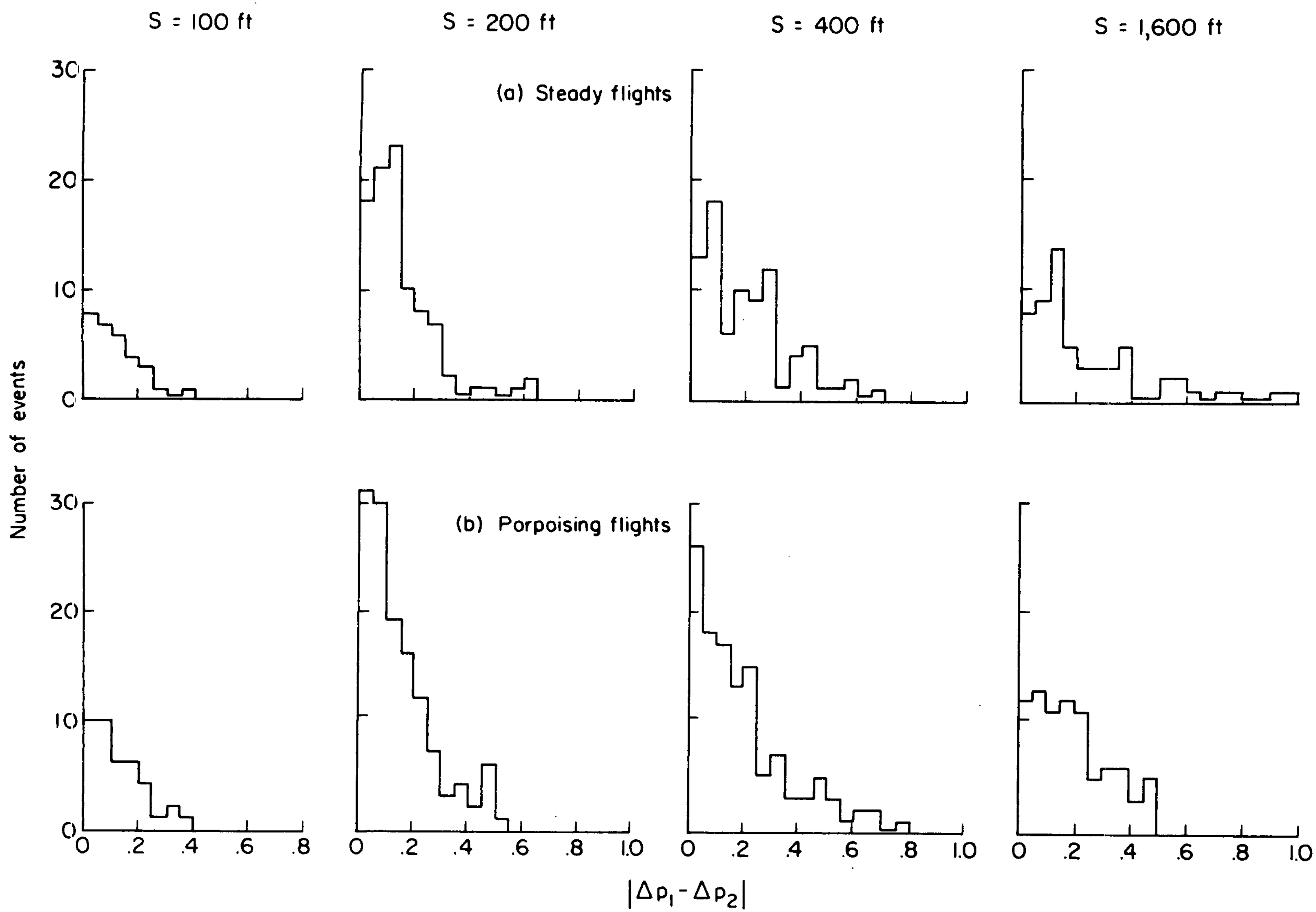


Figure 14.- Histograms of the absolute values of the differences between peak overpressures at points separated in distance from 100 to 1,600 ft., for both steady and porpoising flights.

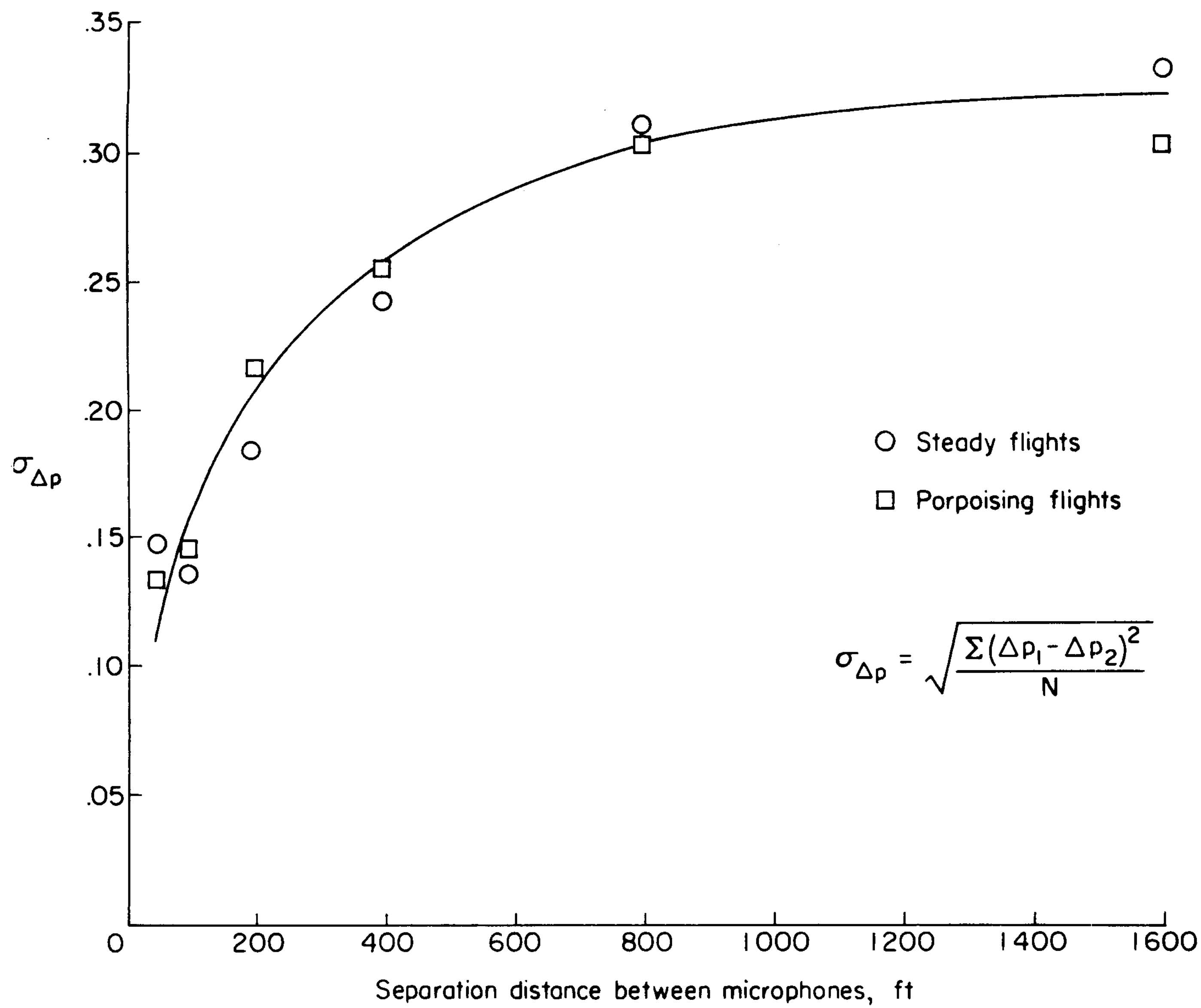


Figure 15.- Root mean square differences in overpressures as a function of separation distance for both steady and porpoising flight.